Possible Catalytic Effects of Ice Particles on the Production of NOx by Lightning Discharges

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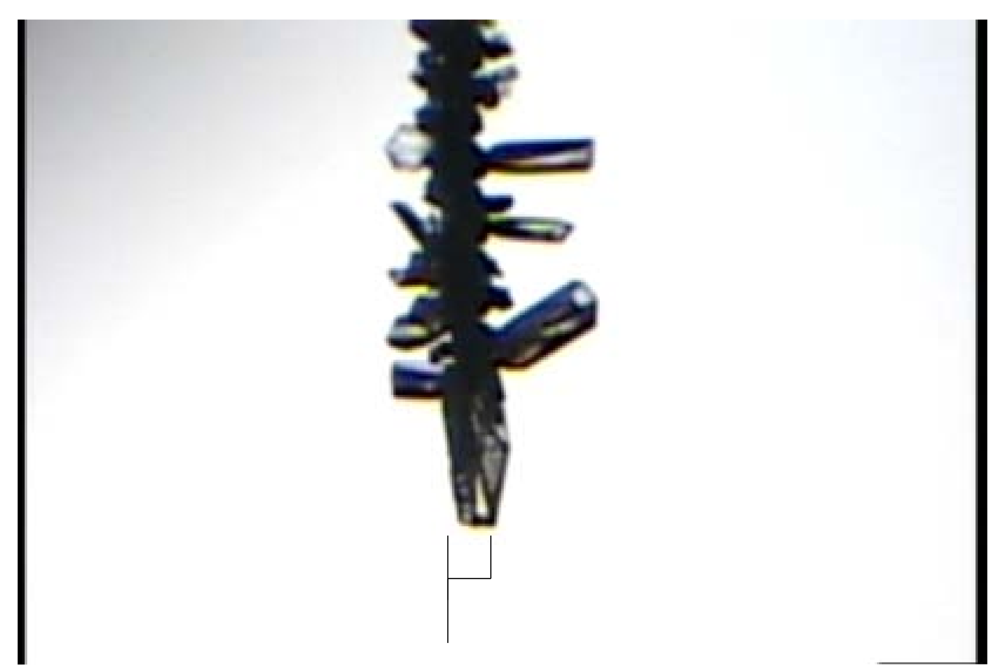
The problem:
Ott et al. (2010) state that IC lightning and CG lightning produce equal amounts of NO_x. Koshak et al. (2011) state that CG lightning produces more NO_x than IC lightning.

Proposed solution: Ice crystals, only present in the upper sections of thunderstorm clouds, catalyze NO_x production, making it appear that IC lightning's contribution rises to the level of CG lightning NO_x.

Proposed mechanism: Chemisorption of nitrogen atoms by water molecules on the surface of ice crystals

Assumptions:
-Dendrites of mass 10^{-8} g
-10^5 ice crystals/m^3
-Nitrogen atoms produced in hot core (ice crystals destroyed here), chemisorbed in corona sheath

Results:
-with hot core at 4000 K, uncatalyzed production rates; ice crystals consume N atoms
-with hot core at 3000 K and below, catalyzed production rates are much higher than uncatalyzed production rates (an order of magnitude greater at 3000 K, several orders of magnitude more at 2000 K)
-with a crystal density of 10 crystals/m^3, uncatalyzed production rates are higher than catalyzed production rates due to the competing effect of lower temperature of N atoms bound to ice crystal surface
The hot core spends more time at lower temperatures; therefore, overall catalyzed production will be greater than uncatalyzed production



50 μm

Sample ice crystals, taken from Peterson et al. (2010)

Temperature	Uncatalyzed NO	Catalyzed NO	Catalyzed NO with smaller ice crystal concentration	Catalyzed NO with hydrogen bonding
2000 K	Limited production	3.77×10^{-7} s	3.76×10^{-3} s	3.76×10^{-7} s
3000 K	2.60×10^{-6} s	2.81×10^{-7} s	2.81×10^{-3} s	2.50×10^{-7} s
4000 K	1.49×10^{-10} s	NO consumption	NO consumption	1.9×10^{-7} s

Table of preliminary results, detailing how quickly available nitrogen is converted to NO within the corona sheath. For the uncatalyzed reaction, little NO is produced at 4000 K as dissociation into N and O is favored, while little NO is produced at 2000 K due to unfavorability of oxygen atoms over oxygen molecules. For the catalyzed reaction, chemisorption of N onto the ice crystal surface shifts equilibrium away from NO production in the corona sheath when the hot core is at 4000 K (Peterson and Beasley 2011).

At 4000 ± 200 K there is insufficient time to mix fresh air into the cylinder, and NO production is roughly limited to the available nitrogen in the cylinder. At 2000 ± 200 K the channel has 2.5 mixing times to bring in fresh air (assuming a mixing time of 10 ms). With the continued consumption of all available nitrogen, catalyzed NO production is expected to be 3.5 times the amount we calculated in the cylinder (from the original nitrogen atoms available plus the extra nitrogen molecules mixed in and dissociated), while uncatalyzed NO production at 4000 K would only be 1.3 times the amount calculated for the cylinder. Both catalyzed and uncatalyzed production at 3000 K consumes all available nitrogen atoms, so there would not be a difference in NO produced from the processes at this temperature. Therefore, using the temperatures 2000, 3000, and 4000 K, ice crystal catalysis is expected to produce 3.5/1.3= 2.7 times more NO than if ice crystals were not present (Peterson and Beasley 2011).

References:
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